APPENDIX C
EVALUATION OF HUMAN HEALTH IMPACTS FROM FACILITY ACCIDENTS

C.1 INTRODUCTION

Accident analyses were performed to estimate the impacts to workers and the public from reasonably foreseeable accidents for the Los Alamos National Laboratory (LANL) Chemistry and Metallurgy Research Building Replacement (CMRR) project alternatives. The analyses were performed in accordance with U.S. Department of Energy (DOE) National Environmental Policy Act (NEPA) guidelines, including the process followed for the selection of accidents, definition of accident scenarios, and estimation of potential impacts. The sections that follow describe the methodology and assumptions, accident selection process, selected accident scenarios, and consequences and risks of the accidents evaluated.

C.2 OVERVIEW OF METHODOLOGY AND BASIC ASSUMPTIONS

The radiological impacts from accidental releases from the facilities used to perform chemistry and metallurgy research (CMR) operations were calculated using the MACCS computer code, Version 1.12 (MACCS2). A detailed description of the MACCS model is provided in NUREG/CR-6613. The enhancements incorporated in MACCS2 are described in the *MACCS2 Users Guide* (NRC 1998). This section presents the MACCS2 data specific to the accident analyses. Additional information on the MACCS2 code is provided in Section C.8.

As implemented, the MACCS2 model evaluates doses due to inhalation of airborne material, as well as external exposure to the passing plume. This represents the major portion of the dose that an individual would receive because of a facility accident. The longer-term effects of radioactive material deposited on the ground after a postulated accident, including the resuspension and subsequent inhalation of radioactive material and the ingestion of contaminated crops, were not modeled for this environmental impact statement (EIS). These pathways have been studied and found to contribute less significantly to the dosage than the inhalation of radioactive material in the passing plume; they are also controllable through interdiction. Instead, the deposition velocity of the radioactive material was set to zero, so that material that might otherwise be deposited on surfaces remained airborne and available for inhalation. Thus, the method used in this EIS is conservative compared with dose results that would be obtained if deposition and resuspension were taken into account.

The impacts were assessed for the offsite populations surrounding each candidate site for the new CMRR Facility and the existing CMR Building, as well as a maximally exposed offsite individual, and noninvolved worker. The impacts to involved workers, those working in the facility where the accident occurs, were addressed qualitatively because no adequate method exists for calculating meaningful consequences at or near the location where the accident could occur. Involved workers are also fully trained in emergency procedures, including evacuation and personal protective actions in the event of an accident.

The offsite population is defined as the general public residing within 50 miles (80 kilometers) of each site. The population distribution for each proposed site is based on U.S. Department of Commerce state population projections (DOC 1999). State and county population estimates were examined to interpolate the data to the year 2002. These data were fitted to a polar coordinate grid with 16 angular sectors aligned with the 16 compass directions, with radial intervals that extend outward to 50 miles (80 kilometers). The offsite population within 50 miles (80 kilometers) of TA-3 was estimated to be 302,130 persons (No Action Alternative); 309,154 persons for TA-55 (Alternative 1 [Preferred Alternative] and Alternative 3); and 315,296 persons for TA-6 (Alternatives 2 and 4). For this analysis, no credit was taken for emergency response evacuations and other mitigative actions such as temporary relocation of the public.

The maximally exposed offsite individual is defined as a hypothetical individual member of the public who would receive the maximum dose from an accident. This individual is usually assumed located at a site boundary. However, because there are public sites within the LANL site boundary, the maximally exposed individual could be at an onsite location.

The maximally exposed offsite individual location was determined for each alternative. The maximally exposed individual location can vary at LANL based on accident conditions. For this analysis, the maximally exposed offsite individual is located 0.75 miles (1.2 kilometers) north-northeast from TA-3, 1.1 miles (1.7 kilometers) north-northeast from TA-55, and 1.2 miles (1.9 kilometers) east-northeast from TA-6.

A noninvolved worker is defined as an onsite worker who is not directly involved in facility activities where the accident occurs. The noninvolved worker is conservatively assumed to be exposed to the full release, without any protection, located at a distance of 304 yards (278 meters) from TA-3, 240 yards (219 meters) from TA-55, and 264 yards (241 meters) from TA-6. Workers would respond to a site emergency alarm and evacuate to a designated shelter area, reducing their exposure potential. For purposes of the analyses, however, no credit was taken for any reduced impacts afforded by evacuation.

Doses to the offsite population, the maximally exposed offsite individual, and a noninvolved worker were calculated based on site-specific meteorological conditions. Site-specific meteorology is described by one year of hourly wind speed atmospheric stability and by rainfall recorded at each site. The MACCS2 calculations produce distributions based on the meteorological conditions. For these analyses, the results presented are based on mean meteorological conditions. The mean produces more realistic consequences than a 95th percentile condition, which is sometimes used in safety analysis reports. The 95th percentile condition represents low-probability meteorological conditions that are not exceeded more than 5 percent of the time.

As discussed in Appendix B, the probability coefficients for determining the likelihood of a latent cancer fatality for low doses or dose rates are 0.0004 and 0.0005 fatal cancers per rem, applied to individual workers and maximum exposed offsite individual, respectively. For high doses or dose rates, respective probability coefficients of 0.0008 and 0.001 fatal cancers per rem were applied for any individual. The higher-probability coefficients apply where individual doses are above 20 rem.

The preceding discussion focuses on radiological accidents. Chemical accident scenarios were not evaluated, since inventories of hazardous chemicals to support CMR operations do not exceed the Threshold Planning Quantities as stipulated on the Extremely Hazardous Substances List provided in Section 3.02 of the Emergency Planning and Community Right-to-Know Act (EPA 1998). Industrial accidents were evaluated and the results are presented in Section C.7.

C.3 Accident Scenario Selection Process

In accordance with DOE NEPA guidelines, this EIS contains to the extent applicable, a representative set of accidents that include various types such as fire, explosion, mechanical impact, criticality, spill, human error, natural phenomena, and external events. DOE's Office of NEPA Policy and Compliance, in the *Recommendations for Analyzing Accidents under the National Environmental Policy Act*, July 2002 (DOE 2002a), provides guidance for preparing accident analyses in environmental impact statements. The guidance clarifies and supplements *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements*, which the Office of NEPA Oversight issued in May 1993 (DOE 1993).

The accident scenario selection was based on evaluation of accidents reported in the *CMR Basis for Interim Operations* (*CMR BIO)* (LA-CP-98-142) (DOE 2002b) and data provided by LANL (LANL 2002). The selection and evaluation of accidents was based on a process described in the *DOE Standard: Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses (Nonreactor SAR Preparation Guide)* (DOE 1994a). The accident selection process for this EIS is described in Sections C.3.1 through C.3.3 for Steps 1 through 3, respectively.

C.3.1 Hazard Identification – Step 1

Hazard identification, or hazards analysis, is the process of identifying the material, system, process, and plant characteristics that can potentially endanger the health and safety of workers and the public and then analyzing the potential human health and safety consequences of accidents associated with the identified hazards. The hazards analysis examines the complete spectrum of accidents that could expose members of the public, onsite workers, facility workers, and the environment to hazardous materials. Hazards that could be present in the new CMRR Facility were identified by reviewing data in source documents (*CMR BIO* and LANL 2002), assessing their applicability to the existing CMR Building, and identifying the potential hazards posed by the CMR activities that would be carried out in the new CMRR Facility.

Hazards analyses were prepared by UC at LANL, which involved collecting and reviewing documentation pertinent to CMR operations. Twenty-seven CMR processes were examined. **Table C–1** indicates the range of CMR processes investigated and assessed for inclusion in the hazards analysis.

Table C–1 CMR Activities Evaluated in the Hazards Analysis

Process	*Process*
Mass Spectroscopy	Mixed Oxide Fuel Pin Fabrication
Gas Generation Matrix Depletion	Plutonium Rolling
Seal-Tube Neutron Generator Operations	Radioactive Source Recovery Process
Uranium Process Chemistry	Material Receipt, Storage, and Transfer
Synthesis of Nonradioactive, Inorganic Compounds	Waste Handling
Magnetic Isotope Separation	Plutonium Assay
Target Fabrication	Actinide Spectroscopy
Hanford Site Tank Remediation	Material Characterization
Glass Encapsulation	Waste Handling
Uranium Hexafluoride	Waste Compaction
Mechanical Testing of Pu and Pu Alloys	Enriched Uranium Foundry
Trace Element Analysis	Standards Laboratory
Special Furnace Operations	Enriched Uranium Extrusion
Thermal Processing/Dilatometry and Immersion	

The result of the hazards identification step was the preparation of hazard tables containing 326 potential hazards applicable to CMR processes.

C.3.2 Hazard Evaluation – Step 2

The subset of approximately 326 major radiological hazards developed in Step 1 was subsequently screened. Using a hazards analysis process based on guidance provided by the *Nonreactor SAR Preparation Guide* (DOE 1994a), the major hazards were reduced to 21 major accidents. The process ranks the risk of each hazard based on estimated frequency of occurrence and potential consequences to screen out low-risk hazards.

C.3.3 Accidents Selected for This Evaluation – Step 3

The subset of 21major accidents was further screened to select a spectrum of accident scenarios for the *CMRR EIS* alternatives. Screening criteria used in the selection process included, but were not limited to: (1) consideration of the impacts to the public and workers of high-frequency/low-consequence accidents and low-frequency/high-consequence accidents; (2) selection of the highest-impact accident in each accident category to envelope the impacts of all potential accidents; and (3) consideration of only reasonably foreseeable accidents. In addition, hazards and accident analyses for the alternatives were reviewed to determine the potential for accidents initiated by external events (e.g., aircraft crash, and explosions in collocated facilities) and natural phenomena (e.g., external flooding, earthquake, extreme winds, and missiles). Accident scenarios initiated by human error are also evaluated in this EIS.

The results of the Step-3 selection process are presented below.

Fire—Fires that occur in the facility can lead to the release of radioactive materials with potential impacts to workers and the public. Initiating events may include internal process and human error events, natural phenomena, such as an earthquake, or external events, such as an airplane crash into the facility. Combustibles near an ignition source can be ignited in a laboratory room containing the largest amounts of radioactive material. The fire may be confined to the laboratory room, propagate uncontrolled and without suppression to adjacent laboratory areas or lead to a facility-wide fire. A fire or deflagration in a HEPA filter can also occur due to an exothermic reaction involving reactive salts and other materials.

Explosion—Explosions that occur in the facility can lead to the release of radioactive materials with potential impacts to workers and the public. Initiating events may include internal process and human error events, natural phenomena such as an earthquake, or external events such as an explosive gas transportation accident. Explosions can disperse nuclear material as well as initiate fires that can propagate throughout the facility. An explosion of methane gas followed by a fire in a laboratory area can potentially propagate to other laboratory areas and affect the entire facility.

Spills—Spills of radioactive and/or chemical materials can be initiated by failure of process equipment and/or human error, natural phenomenal or external events. Radioactive and chemical materials spills typically involve laboratory room quantities of materials that are relatively small compared to releases caused by fires and explosions. Laboratory room spills could impact members of the public but may be a more serious risk to the laboratory room workers. Larger spills involving vault size quantities are also possible.

Criticality—The potential for a criticality exists whenever there is a sufficient quantity of nuclear material in an unsafe configuration. Although a criticality could impact the public, its effects are primarily associated with workers near the accident. For the *CMRR EIS* alternatives, the likelihood of an unsafe configuration and criticality is sufficiently small to exclude it from detailed consideration in the EIS.

Natural Phenomena—The potential accidents associated with natural phenomena include earthquakes, high winds, flooding and similar naturally occurring events. For *CMRR EIS* alternatives, a severe earthquake can lead to the release of radioactive materials and exposure of workers and the public. A severe earthquake could cause the collapse of facility structures, falling debris and failure of glove boxes and nuclear materials storage facilities. An earthquake could also initiate a fire that propagates throughout the facility and results in an unfiltered release of radioactive material to the environment. In addition to the potential exposure of workers and the public to radioactive and chemical materials, an accident could also cause human injuries and fatalities from the force of the event, such as falling debris, during an earthquake or the thermal effects of a fire.

Chemical—The quantities of regulated chemicals used and stored in the facility are well below the threshold quantities set by the EPA (40 CFR 68), and pose minimal potential hazards to the public health and the environment in an accident condition. Accidents involving small laboratory quantities of chemicals are primarily a risk to the involved worker in the immediate vicinity of the accident. There will be no bulk quantities of chemicals stored at the new CMRR Facility.

Airplane Crash—The potential exists for an airplane crash into the new CMRR Facility. The probability of an airplane crash during over flight is less than 10^{-6} and under DOE NEPA guidelines does not have to be considered in the EIS. During landing and takeoff operations at the local Los Alamos airport, there is a reasonable probability of a small commercial or military airplane crashing into the facility. However, the impacts of a small airplane crash into the facility are bounded by other accidents addressed in this EIS.

C.4 ACCIDENT SCENARIO DESCRIPTIONS AND SOURCE TERM

This section describes the accident scenarios and corresponding source term developed for the *CMRR EIS* alternatives. The spectrum of accidents described in this section was used to determine, for workers and the public, the consequences and associated risks for each alternative. Assumptions were made when further information was required to clarify the accident condition, update some of the parameters, or facilitate the evaluation process; these are referenced in each accident description.

The source term is the amount of respirable radioactive material released to the air, in terms of curies or grams, assuming the occurrence of a postulated accident. The airborne source term is typically estimated by the following equation:

Source term = material at risk × damage ratio × airborne release fraction × respirable fraction × leak path factor

where:

MAR = material at risk
DR = damage ratio
ARF = airborne release fraction
RF = respirable fraction
LPF = leak path factor

The material at risk is the amount of radionuclides (in curies of activity or grams for each radionuclide) available for release when acted upon by a given physical stress or accident. The material at risk is specific to a given process in the facility of interest. It is not necessarily the total quantity of material present, but is that amount of material in the scenario of interest postulated to be available for release.

The damage ratio is the fraction of material exposed to the effects of the energy, force, or stress generated by the postulated event. For the accident scenarios discussed in this analysis, the value of the damage ratio varies from 0.1 to 1.0.

The airborne release fraction is the fraction of material that becomes airborne due to the accident. In this analysis, airborne release fractions were obtained from the *CMR BIO*, data supplied by LANL (LANL 2002), or the *DOE Handbook* on airborne release fractions (DOE 1994b).

The respirable fraction is the fraction of the material with a 0.0004 inches (10-microns) or less aerodynamic-equivalent diameter particle size that could be retained in the respiratory system following inhalation. The respirable fraction values are also taken from the *CMR BIO*, data supplied by LANL (LANL 2002), or the *DOE Handbook* on airborne release fractions (DOE 1994b).

The leak path factor accounts for the action of removal mechanisms, for example, containment systems, filtration, and deposition, to reduce the amount of airborne radioactivity ultimately released to occupied spaces in the facility or the environment. A leak path factor of 1.0 (no reduction) is assigned in accident scenarios involving a major failure of confinement barriers. Leak path factors were obtained from the *CMR BIO*, data supplied by LANL (LANL 2002), and site-specific evaluations.

Since the isotopic composition and shape of some of the nuclear materials are classified, the material inventory has been converted to equivalent amounts of plutonium-239. The conversion was on a constant-consequence basis, so that the consequences calculated in the accident analyses are equivalent to what they would be if actual material inventories were used. The following sections describe the selected accident scenarios and corresponding source terms for the alternatives.

C.4.1 New CMRR Facility Alternatives

The accidents described in this section pertain to the new CMRR Facility at TA-55 and TA-6.

Facility-Wide Fire—The accident scenario postulates that combustible material near an ignition source are ignited in a laboratory area or vault containing large amounts of radioactive materials. The fire could be initiated by natural phenomena, human error, or equipment failure. The fire is assumed to propagate uncontrolled and without suppression to adjacent laboratory areas and the entire facility. The material at risk is estimated to be approximately 13,228 pounds (6,000 kilograms) of plutonium-239 equivalent in the form of metal (95 percent) and liquid (5 percent). The scenario conservatively assumes the damage ratio and leak path factors are 1.0. No credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio and leak path factors to be less than 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is estimated to be 0.00025 for metal and 0.002 for liquid. The source term for radioactive material released to the environment is 3.14 pounds (1.43 kilograms) of plutonium-239 metal and 1.32 pounds (0.6 kilograms) of plutonium-239 liquid. The frequency of the accident is estimated to be less than 0.000005 and is conservatively assumed at 5.0×10^{-6} per year for risk calculation purposes.

Process Fire—The accident scenario postulates combustibles near an ignition source are ignited in a laboratory area containing radioactive materials. The fire is assumed to propagate uncontrolled and without suppression throughout the laboratory area but does not propagate to other laboratory areas. The material at risk is estimated to be 66.15 pounds (30 kilograms) of plutonium-239 equivalent in the form of liquid. The scenario conservatively assumes the damage ratio is 1.0. The leak path factor is 0.016, and the released respirable fraction (airborne release fraction times respirable fraction) is estimated to be 0.002. The resulting source term of radioactive material released to the environment is estimated to be 0.034 ounces (0.96 grams) of plutonium-239 liquid. The frequency of the accident is estimated to be in the range of 0.0001 to 0.001 per year and is conservatively assumed to be 0.001 per year for risk calculation purposes.

Fire in the Main Vault—This accident postulates a fire in the main vault. In this scenario, the main vault door is accidentally left open and a fire inside the vault or propagating to the main vault engulfs the entire contents of plutonium. The material at risk is estimated to be 12,568 pounds (5,700 kilograms) of plutonium-239 equivalent in metal form. The scenario conservatively assumes the damage ratio and leak path factors are 1.0. No credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio and leak path factors to be less than 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is estimated to be 0.00025. The resulting source term of radioactive material released to the environment is estimated to be 3.14 pounds (1.43 kilograms) of plutonium-239 metal. The frequency of the accident is estimated to be 0.000001.

Process Explosion—This accident postulates an explosion of methane gas present in the process followed by a fire in a laboratory area containing radioactive materials. The material at risk is 15.88 pounds (7.2 kilograms) of plutonium equivalent in powder form. The damage ratio is conservatively assumed at 1.0. The leak path factor is estimated to be 0.016. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.0015. The resulting source term of radioactive material released to the environment is estimated at 0.006 ounces (0.17 grams) of plutonium-239 powder. The frequency of the accident is estimated to be in the range of 0.0001 to 0.001 per year and is conservatively assumed to be 0.001 per year for risk calculation purposes.

Process Spill—This accident postulates a spill of radioactive material in the process area caused by human error or equipment failure. The material at risk is estimated at 15.88 pounds (7.2 kilograms) of plutonium-239 equivalent in powder form. The damage ratio is assumed to be 1.0. The leak path factor estimated to be 0.016. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.002. The resulting source term of radioactive material released to the environment is estimated at 0.0081 ounces (0.23 grams) of plutonium-239 powder. The frequency of the accident is estimated to be in the range of 0.05 and 0.1 per year and is conservatively assumed to be 0.1 per year for risk calculation purposes.

Seismic-Induced Laboratory Spill—An earthquake is postulated to occur that exceeds the Performance Category-3 design capability of the facility. Internal enclosures topple and are damaged by falling debris. The material at risk is estimated to be 661.5 pounds (300 kilograms) of plutonium-239 in powder form. The scenario conservatively assumes the damage ratio and leak path factors are 1.0. No credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio and leak path factors to be less than 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.002 for powder. The source term for radioactive material released to the environment is 1.32 pounds (0.6 kilograms) of plutonium-239 powder. The frequency of the accident is estimated to be in the range of 0.00001 to 0.0001 per year and is conservatively assumed to be 0.0001 per year for risk calculation purposes.

Seismic-Induced Fire—An earthquake is postulated to occur that exceeds the Performance Category-3 design capability of the facility. Internal enclosures topple and are damaged by falling debris. Combustibles in the facility are ignited and the fire engulfs radioactive material in the laboratory area. The material at risk is estimated to be 661.5 pounds (300 kilograms) of plutonium-239 in liquid form. The scenario conservatively assumes the damage ratio and leak path factors are 1.0. No credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio and leak path factors to be less than 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.002 for liquid. The source term for radioactive material released to the environment is 1.32 pounds (0.6 kilograms) of plutonium-239 liquid. The frequency of the accident is estimated to be in the range of 0.000001 to 0.00001 per year and is conservatively assumed to be 0.00001 per year for risk calculation purposes.

Facility-Wide Spill—An earthquake is postulated to occur that exceeds the Performance Category-3 design capability of the facility. A vault and process areas containing radioactive material are severely damaged and their plutonium-239 contents in the form of powder spills. The material at risk is estimated to be 13,230 pounds (6,000 kilograms) of plutonium-239 in powder form. The scenario conservatively assumes the damage ratio and leak path factors are 1.0. No credit is taken for equipment and facility features and mitigating factors that could cause the damage ratio and leak path factors to be less than 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.002 for powder. The source term for radioactive material released to the environment is 26.461 pounds (12 kilograms) of plutonium-239 powder. The frequency of the accident is estimated to be less than 5.0×10^{-6} and is conservatively assumed at 5.0×10^{-6} per year for risk calculation purposes.

C.4.2 No Action Alternative

The accidents described in this section pertain to the No Action Alternative.

Wing-Wide Fire—The accident scenario postulates combustibles in the vicinity of an ignition source are ignited in a laboratory area containing the largest amounts of radioactive materials. The fire is assumed to propagate uncontrolled and without suppression to adjacent laboratory areas an entire facility wing. The material at risk is estimated at 13.23 pounds (6 kilograms) of plutonium-239 equivalent in the form of metal (20 percent), powder (40 percent) and solution (40 percent). The scenario conservatively assumes the damage ratio and leak path factors are 1.0, and the released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.017. The frequency of the accident is estimated to be 0.00005 per year.

HEPA Filter Fire—A fire or deflagration is assumed to occur in the HEPA filters due to an exothermic reaction involving reactive lasts or other materials. Two filters containing 0.18 ounces (5 grams) of plutonium-239 equivalent each are affected. The material at risk is estimated at 0.35 ounces (10 grams) of plutonium-239 equivalent in the form of oxide particles. The damage ratio and leak path factors are conservatively assumed at 1.0 and the released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.4. The resulting source term of radioactive material released to the environment is estimated at 0.14 ounces (4 grams) of plutonium-239 equivalent. The frequency of the accident is estimated to be in the range of 0.0001 to 0.01 and is conservatively assumed to be 0.01 per year for risk calculation purposes.

Fire in the Main Vault—This accident postulates a fire in the main vault. In this scenario, the main vault door is accidentally left open and a fire inside the vault or propagating to the main vault engulfs the entire contents of plutonium. The material at risk is estimated at 440.92 pounds (200 kilograms) of plutonium-239 equivalent. The damage ratio and leak path factors are conservatively assumed at 1.0 and the released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.002. The resulting source term of radioactive material released to the environment is estimated at 14.11 ounces (400 grams) of plutonium-239 equivalent. The frequency of the accident is estimated to be less than 1.0×10^{-6} per year and is conservatively assumed to be 1.0×10^{-6} per year for risk calculation purposes.

Flammable Gas Explosion—This accident postulates an explosion of methane gas followed by a fire in a laboratory area containing radioactive materials. The material at risk is 8.75 pounds (3.97 kilograms) of plutonium-239 equivalent. The damage ratio is conservatively assumed at 1.0. The leak path factor is assumed at 0.68. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.005. The resulting source term of radioactive material released to the environment is estimated at 0.48 ounces (13.5 grams) of plutonium-239 equivalent. The frequency of the accident is estimated to be in the range of 1.0×10^{-6} to 0.0001 per year and is conservatively assumed to be 0.0001 per year for risk calculation purposes.

Propane/Hydrogen Transport Explosion—An accidental explosion is postulated to occur during the onsite transportation of propane or hydrogen near the CMR Building. The vehicle accident results in the breach of gas containers followed by ignition and explosion of the gas causing damage to the facility and affecting some radioactive materials. The material at risk is estimated at 26.90 pounds (12.2 kilograms) of plutonium-239 equivalent. The damage ratio is conservatively assumed at 1.0 and the leak path factor is 0.3. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.005. The resulting source term of radioactive material released to the environment is estimated at 0.65 ounces (18.3 grams) of plutonium-239 equivalent. The frequency of the accident is estimated to be less than 1.0×10^{-6} per year and is conservatively assumed to be 1.0×10^{-6} per year for risk calculation purposes.

Radioactive Spill—This accident postulates a spill of radioactive material caused by human error. The accident involves the spill of plutonium-238 while work is done outside of confinement. The accident potentially impacts workers as well as the public. The material at risk for public impacts is estimated at 0.0000529 ounces (0.0015 grams) of plutonium-238. The damage ratio and leak path factor are conservatively assumed at 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.05. The resulting source term of radioactive material released to the environment is estimated at 2.65×10^{-6} ounces (0.000075 grams) of plutonium-238. The frequency of the accident is estimated at 0.1 per year.

Natural Gas Pipeline Rupture—This accident postulates the accidental rupture of a natural gas pipeline near the CMR Building. The released natural gas initiates a flammable gas explosion and a wing-wide fire. The material at risk is 13.23 pounds (6 kilograms) of plutonium-239 equivalent. The damage ratio and leak path factor are conservatively assumed at 1.0. The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.017. The source term for radioactive material released to the environment 3.56 ounces (101 grams) of plutonium-239 equivalent. The frequency of the accident is estimated at 1.0×10^{-7} per year.

Severe Earthquake—A large earthquake is postulated to occur that exceeds design capability of the facility. It is assumed that all internal enclosures topple and are damage by falling debris and that the hot cells fail. All radioactive material in the hot cells is at risk of being released. The material at risk is estimated at 44.53 pounds (20.2 kilograms) of plutonium-239 equivalent composed of metal (20 percent), powder (40 percent), and solution (40 percent). The released respirable fraction (airborne release fraction times respirable fraction) is estimated at 0.005. The source term for radioactive material released to the environment 3.56 ounces (101 grams) of plutonium-239 equivalent. The frequency of the accident is estimated at 0.0024 per year.

C.5 Accident Analyses Consequences and Risk Results

The consequences of a radiological accident to workers and the public can be measured in a number of ways depending on the application. Three measures are used in this EIS. The first measure of consequences is individual dose expressed in terms of rem or millirem for a member of the public or worker and collective dose expressed in terms of person-rem for members of the public or a population of workers. The second measure is a post-exposure effect that reflects the likelihood of latent cancer fatality for an exposed individual or the expected number of latent cancer fatalities in a population of exposed individuals. Individual or public exposure to radiation can only occur if there is an accident involving radioactive materials, which leads to the third measure. The third measure of accident consequences is referred to as risk that takes into account the probability (or frequency) of the accident's occurrence. Risk is the mathematical product of the probability or frequency of accident occurrence and the latent cancer fatality consequences. Risk is calculated as follows:

$R_i = D_i \times F \times P$ for an individual
$R_p = D_p \times F \times P$ for the population

where,

R_i – is the risk of a latent cancer fatality for an individual receiving a dose D_i
R_p – is the risk of a number of latent cancer fatalities for a population receiving a dose D_p
D_i – the dose in rem to an individual or a worker
D_p – the dose in person-rem to a population of individuals or workers
F = dose-to-latent cancer fatality conversion factor which is 0.0005 latent cancer fatalities per rem or person-rem for members of the public and 0.0004 latent cancer fatalities per rem or person-rem for workers
P = the probability or frequency of the accident usually expressed on a per year basis.

Once the source term, the amount of radioactive material released to the environment for each accident scenario is determined, the radiological consequences are calculated. The calculations and resulting impacts vary depending on how the radioactive material release is dispersed, what materials are involved, and which receptors are being considered.

For example, if the dose to the maximally exposed individual is 10 rem, the probability of a latent cancer fatality for an individual is 10 × 0.0005 = 0.005, where 0.0005 is the dose-to-latent cancer fatality conversion factor. If the maximally exposed individual receives a dose exceeding 20 rem, the dose-to-latent cancer fatality conversion factor is doubled to 0.001. Thus, if the maximally exposed individual receives a dose of 30 rem, the probability of a latent cancer fatality is 30 × 0.001 = 0.03. For an individual, the calculated probability of a latent cancer fatality is in addition to the probability of cancer from all other causes.

For a noninvolved worker, the dose-to-latent cancer fatality conversion factor is 0.0004, rather than the 0.0005 factor used for the public, reflecting the differences in work force composition compared to the public. If a noninvolved worker receives a dose of 10 rem, the probability of a latent cancer fatality is 10 × 0.0004 = 0.004. As with the maximally exposed individual, if the dose exceeds 20 rem, the latent cancer probability factor doubles to 0.008.

For the population, the same dose-to-latent cancer fatality conversion factors are used to determine the estimated number of latent cancer fatalities. The calculated number of latent cancer fatalities in the population is in addition to the number of cancer fatalities that would result from all other causes. The MACCS2 computer code calculates the dose to each individual in the exposed population and then applies the appropriate dose-to-latent cancer fatality conversion factor to estimate the latent cancer fatality consequences. In other words, 0.0005 for doses less than 20 rem or 0.001 for doses greater than or equal to 20 rem. Therefore, for some accidents, the estimated number of latent cancer fatalities will involve both dose-to-latent cancer fatality conversion factors. This indicates that some members of the population received doses in excess of 20 rem.

The following tables provide the accident consequences for each alternative. For each alternative, there are two tables showing the impacts. The first table presents the consequences (doses and latent cancer fatality and latent cancer fatalities) assuming the accident occurs, that is, not reflecting the frequency of accident occurrence. The second shows accident risks that are obtained by multiplying the latent cancer fatality and latent cancer fatalities values in the first table by the frequency of each accident listed in the first table.

Table C–2 Accident Frequency and Consequences under the No Action Alternative

Accident	Frequency (per year)	Maximally Exposed Offsite Individual		Offsite Population [a]		Noninvolved Worker	
		Dose (rem)	Latent Cancer Fatality [b]	Dose (person-rem)	Latent Cancer Fatalities [c]	Dose (rem)	Latent Cancer Fatality [b]
Wing-wide fire	0.00005	0.55	0.00027	1020	0.51	2.67	0.0011
Severe earthquake	0.0024	2.92	0.0015	1680	0.84	66.9	0.054
Flammable gas explosion	1.0×10^{-6} to 0.0001	0.073	0.000036	135	0.068	0.35	0.00014
HEPA filter fire	0.0001 to 0.01	0.12	0.000058	66.5	0.033	2.65	0.0011
Fire in main vault	$< 1.0 \times 10^{-6}$	2.15	0.0011	4000	2.0	10.5	0.0042
Propane/hydrogen transport explosion	$< 1.0 \times 10^{-6}$	0.53	0.00027	304	0.15	12.1	0.0048
Natural gas pipeline rupture	1.0×10^{-7}	0.55	0.00027	1020	0.51	2.67	0.0011
Radioactive spill	0.1	0.00054	3.0×10^{-7}	0.31	0.00016	0.012	5.0×10^{-6}

a Based on a population of 302,130 persons residing within 50 miles (80 kilometers) of the site.
b Increased likelihood of latent cancer fatality for an individual assuming the accident occurs.
c Increased number of latent cancer fatalities for the offsite population assuming the accident occurs.

Table C–3 Accident Risks under the No Action Alternative

Accident	Risk of Latent Cancer Fatality		
	Maximally Exposed Offsite Individual [a]	Offsite Population [b, c]	Noninvolved Worker [a]
Wing-wide fire	1.4×10^{-8}	0.000026	5.5×10^{-8}
Severe earthquake	3.5×10^{-6}	0.002	0.00013
Flammable gas explosion	3.6×10^{-9}	6.8×10^{-6}	1.4×10^{-8}
HEPA filter fire	5.8×10^{-7}	0.00033	0.000011
Fire in main vault	1.1×10^{-9}	2.0×10^{-6}	4.2×10^{-9}
Propane/hydrogen transport explosion	2.7×10^{-10}	1.5×10^{-7}	4.8×10^{-9}
Natural gas pipeline rupture	2.7×10^{-11}	5.1×10^{-8}	1.1×10^{-10}
Radioactive spill	3.0×10^{-8}	0.000016	5.0×10^{-7}

a Risk of increased likelihood of a latent cancer fatality to the individual.
b Risk of the increased number of latent cancer fatalities for the offsite population.
c Based on a population of 302,130 persons residing within 50 miles (80 kilometers) of the site.

Table C–4 Accident Frequency and Consequences under Alternative 1

Accident	Frequency (per year)	Maximally Exposed Offsite Individual		Offsite Population [a]		Noninvolved Worker	
		Dose (rem)	Latent Cancer Fatality [b]	Dose (person-rem)	Latent Cancer Fatalities [c]	Dose (rem)	Latent Cancer Fatality [b]
Facility-wide fire	5.0×10^{-6}	7.0	0.0035	17,029	8.5	51.4	0.041
Process fire	0.001	0.004	2.0×10^{-6}	9.78	0.0049	0.03	0.000012
Fire in the main vault	1.0×10^{-6}	5.92	0.003	14,500	7.25	43.88	0.035
Process explosion	0.001	0.0036	1.8×10^{-6}	2.5	0.0013	0.15	0.000059
Process spill	0.1	0.0046	2.3×10^{-6}	3.19	0.0016	0.19	0.000076
Seismic-induced laboratory spill	0.0001	12.1	0.0061	8,394	4.2	495	0.4
Seismic-induced fire	0.00001	2.5	0.0013	6,110	3.1	18.5	0.0074
Facility-wide spill	5.0×10^{-6}	243.1	0.24	167,705	83.9	9,352	1.0

a Based on a population of 309,154 persons residing within 50 miles (80 kilometers) of the site.
b Increased likelihood of latent cancer fatality for an individual assuming the accident occurs.
c Increased number of latent cancer fatalities for the offsite population assuming the accident occurs.

Table C–5 Accident Risks under Alternative 1

Accident	Risk of Latent Cancer Fatality: Maximally Exposed Offsite Individual [a]	Risk of Latent Cancer Fatality: Offsite Population [b, c]	Risk of Latent Cancer Fatality: Noninvolved Worker [a]
Facility-wide fire	1.7×10^{-8}	0.000043	2.1×10^{-7}
Process fire	2.0×10^{-9}	4.9×10^{-6}	1.2×10^{-8}
Fire in the main vault	3.0×10^{-9}	7.3×10^{-6}	3.5×10^{-8}
Process explosion	1.8×10^{-9}	1.3×10^{-6}	5.9×10^{-8}
Process spill	2.3×10^{-7}	0.00016	7.6×10^{-6}
Seismic-induced laboratory spill	6.4×10^{-7}	0.00044	4.2×10^{-6}
Seismic-induced fire	1.3×10^{-8}	0.000031	7.4×10^{-8}
Facility-wide spill	1.2×10^{-6}	0.00042	0.000038

[a] Risk of increased likelihood of a latent cancer fatality to the individual.
[b] Risk of the increased number of latent cancer fatalities for the offsite population.
[c] Based on a population of 309,154 persons residing within 50 miles (80 kilometers) of the site.

Table C–6 Accident Frequency and Consequences under Alternative 2

Accident	Frequency (per year)	Maximally Exposed Offsite Individual: Dose (rem)	Maximally Exposed Offsite Individual: Latent Cancer Fatality [b]	Offsite Population [a]: Dose (person-rem)	Offsite Population [a]: Latent Cancer Fatalities [c]	Noninvolved Worker: Dose (rem)	Noninvolved Worker: Latent Cancer Fatality [b]
Facility-wide fire	5.0×10^{-6}	4.0	0.002	15,173	7.58	44.98	0.036
Process fire	0.001	0.0023	1.1×10^{-6}	8.71	0.0044	0.026	0.00001
Fire in the main vault	1.0×10^{-6}	3.41	0.0017	12,938	6.47	38.3	0.031
Process explosion	0.001	0.0017	8.3×10^{-7}	2.37	0.0012	0.08	0.000032
Process spill	0.1	0.002	1.1×10^{-6}	3.01	0.0015	0.172	0.000069
Seismic-induced laboratory spill	0.0001	5.54	0.0028	7,920	3.96	453	0.36
Seismic-induced fire	0.00001	1.44	0.00072	5,440	2.72	16.1	0.0065
Facility-wide Spill	5.0×10^{-6}	111.3	0.11	158,000	79.20	9,100	1.0

[a] Based on a population of 315,296 persons residing within 50 miles (80 kilometers) of the site.
[b] Increased likelihood of latent cancer fatality for an individual assuming the accident occurs.
[c] Increased number of latent cancer fatalities for the offsite population assuming the accident occurs.

Table C–7 Accident Risks under Alternative 2

Accident	Risk of Latent Cancer Fatality: Maximally Exposed Offsite Individual [a]	Risk of Latent Cancer Fatality: Offsite Population [b, c]	Risk of Latent Cancer Fatality: Noninvolved Worker [a]
Facility-wide fire	1.0×10^{-8}	0.000038	1.8×10^{-7}
Process fire	1.2×10^{-9}	4.4×10^{-6}	1.0×10^{-8}
Fire in the main vault	1.7×10^{-9}	6.5×10^{-6}	3.1×10^{-8}
Process explosion	8.3×10^{-10}	1.2×10^{-6}	3.2×10^{-8}
Process spill	1.1×10^{-7}	0.00015	6.9×10^{-6}
Seismic-induced laboratory spill	2.8×10^{-7}	0.00038	0.000036
Seismic-induced fire	7.2×10^{-9}	0.000027	6.5×10^{-8}
Facility-wide spill	5.6×10^{-7}	0.0004	0.000036

[a] Risk of increased likelihood of a latent cancer fatality to the individual.
[b] Risk of the increased number of latent cancer fatalities for the offsite population.
[c] Based on a population of 315,296 persons residing within 50 miles (80 kilometers) of the site.

Table C–8 Accident Frequency and Consequences under Alternative 3 (TA-55 Hybrid Alternative)

Accident	Frequency (per year)	Maximally Exposed Offsite Individual		Offsite Population [a]		Noninvolved Worker	
		Dose (rem)	Latent Cancer Fatality [b]	Dose (person-rem)	Latent Cancer Fatalities [c]	Dose (rem)	Latent Cancer Fatality [b]
Facility-wide fire	5.0×10^{-6}	7.0	0.0035	17,029	8.5	51.4	0.041
Process fire	0.001	0.004	2.0×10^{-6}	9.78	0.0049	0.03	0.000012
Fire in the main vault	1.0×10^{-6}	5.92	0.003	14,500	7.25	43.88	0.035
Process explosion	0.001	0.0036	1.8×10^{-6}	2.5	0.0013	0.15	0.000059
Process spill	0.1	0.0046	2.3×10^{-6}	3.19	0.0016	0.19	0.000076
Seismic-induced laboratory spill	0.0001	12.1	0.0061	8,394	4.2	495	0.4
Seismic-induced fire	0.00001	2.5	0.0013	6,125	3.1	18.5	0.0075
Facility-wide spill	5.0×10^{-6}	243.1	0.24	167,705	83.9	9,352	1.0

[a] Based on a population of 309,154 persons residing within 50 miles (80 kilometers) of the site.
[b] Increased likelihood of latent cancer fatality for an individual assuming the accident occurs.
[c] Increased number of latent cancer fatalities for the offsite population assuming the accident occurs.

Table C–9 Accident Risks under Alternative 3 (TA-55 Hybrid Alternative)

Accident	Risk of Latent Cancer Fatality		
	Maximally Exposed Offsite Individual [a]	Offsite Population [b, c]	Noninvolved Worker [a]
Facility-wide fire	1.7×10^{-8}	0.000043	2.1×10^{-7}
Process fire	2.0×10^{-9}	4.9×10^{-6}	1.2×10^{-8}
Fire in the main vault	3.0×10^{-9}	7.3×10^{-6}	3.5×10^{-8}
Process explosion	1.8×10^{-9}	1.3×10^{-6}	5.9×10^{-8}
Process spill	2.3×10^{-7}	0.00016	7.6×10^{-6}
Seismic-induced laboratory spill	6.4×10^{-7}	0.00044	4.2×10^{-6}
Seismic-induced fire	1.3×10^{-8}	0.000031	7.4×10^{-8}
Facility-wide spill	1.2×10^{-6}	0.00042	0.000038

[a] Risk of increased likelihood of a latent cancer fatality to the individual.
[b] Risk of the increased number of latent cancer fatalities for the offsite population.
[c] Based on a population of 309,154 persons residing within 50 miles (80 kilometers) of the site.

Table C–10 Accident Frequency and Consequences under Alternative 4 (TA-6 Hybrid Alternative)

Accident	Frequency (per year)	Maximally Exposed Offsite Individual		Offsite Population [a]		Noninvolved Worker	
		Dose (rem)	Latent Cancer Fatality [b]	Dose (person-rem)	Latent Cancer Fatalities [c]	Dose (rem)	Latent Cancer Fatality [b]
Facility-wide fire	5.0×10^{-6}	4.0	0.002	15,173	7.58	44.98	0.036
Process fire	0.001	0.0023	1.1×10^{-6}	8.71	0.0044	0.026	0.00001
Fire in the main vault	1.0×10^{-6}	3.41	0.0017	12,938	6.47	38.3	0.031
Process explosion	0.001	0.0017	8.3×10^{-7}	2.37	0.0012	0.08	0.000032
Process spill	0.1	0.002	1.1×10^{-6}	3.01	0.0015	0.172	0.000069
Seismic-induced laboratory spill	0.0001	5.54	0.0028	7,920	3.96	453	0.36
Seismic-induced fire	0.00001	1.44	0.00072	5,440	2.72	16.1	0.0065
Facility-wide spill	5.0×10^{-6}	111.3	0.11	158,000	79.2	9,100	1.0

[a] Based on a population of 315,296 persons residing within 50 miles (80 kilometers) of the site.
[b] Increased likelihood of latent cancer fatality for an individual assuming the accident occurs.
[c] Increased number of latent cancer fatalities for the offsite population assuming the accident occurs.

Table C–11 Accident Risks under Alternative 4 (TA-6 Hybrid Alternative)

Accident	*Risk of Latent Cancer Fatality*		
	Maximally Exposed Offsite Individual [a]	*Offsite Population* [b, c]	*Noninvolved Worker* [a]
Facility-wide fire	1.0×10^{-8}	0.000038	1.8×10^{-7}
Process fire	1.2×10^{-9}	4.4×10^{-6}	1.0×10^{-8}
Fire in the main vault	1.7×10^{-9}	6.5×10^{-6}	3.1×10^{-8}
Process explosion	8.3×10^{-10}	1.2×10^{-6}	3.2×10^{-8}
Process spill	1.1×10^{-7}	0.00015	6.9×10^{-6}
Seismic-induced laboratory spill	2.8×10^{-7}	0.00038	0.000036
Seismic-induced fire	7.2×10^{-9}	0.000027	6.5×10^{-8}
Facility-wide spill	5.6×10^{-7}	0.0004	0.000036

[a] Risk of increased likelihood of a latent cancer fatality to the individual.
[b] Risk of the increased number of latent cancer fatalities for the offsite population.
[c] Based on a population of 315,296 persons residing within 50 miles (80 kilometers) of the site.

C.6 ANALYSIS CONSERVATISM AND UNCERTAINTY

The analysis of accidents is based on calculations relevant to postulated sequences of accident events and models used to calculate the accident's consequences. The models provide estimates of the frequencies, source terms, pathways for dispersion, exposures, and the effects on human health and the environment as realistic as possible within the scope of the analysis. In many cases, the rare occurrence of postulated accidents leads to uncertainty in the calculation of the consequences and frequencies. This fact has promoted the use of models or input values that yield conservative estimates of consequences and frequency.

Due to the layers of conservatism built into the accident analysis for the spectrum of postulated accidents, the estimated consequences and risks to the public represent the upper limit for the individual classes of accidents. The uncertainties associated with the accident frequency estimates are enveloped by the conservatism in the analysis.

Of particular interest are the uncertainties in the estimates of cancer fatalities from exposure to radioactive materials. The numerical values of the health risk estimators used in this EIS were obtained by linear extrapolation from the nominal risk estimate for lifetime total cancer mortality resulting from exposures of 10 rad. Because the health risk estimators are multiplied by conservatively calculated radiological doses to predict fatal cancer risks, the fatal cancer values presented in this EIS are expected to be conservative estimates.

C.7 INDUSTRIAL SAFETY

Estimates of potential industrial impacts on workers during construction and operations were evaluated based on DOE and U.S. Bureau of Labor Statistics. Impacts are classified into two groups, total recordable cases and fatalities. A recordable case includes work-related fatality, illness, or injury that resulted in loss of consciousness, restriction of work or motion, transfer to another job, or required medical treatment beyond first aid.

DOE and contractor total recordable cases and fatality incidence rates were obtained from the CAIRS database (DOE 2000a, 2000b). The CAIRS database is used to collect and analyze DOE and DOE contractor reports of injuries, illnesses, and other accidents that occur during DOE operations. The five-year average (1995 through 1999) rates were determined for average construction total recordable cases, average operations total recordable cases, and average operations fatalities. The average construction fatality rate was obtained from the Bureau of Labor Statistics (Toscano and Windau 1998).

Table C–12 presents the average occupational total recordable cases and fatality rates for construction and operations activities.

Table C–12 Average Occupational Total Recordable Cases and Fatality Rates (per worker year)

Labor Category	*Total Recordable Cases*	*Fatalities*
Construction	0.053	0.00014
Operations	0.033	0.000013

Expected annual construction and operations impacts on workers for each alternative are presented in **Table C–13**.

Table C–13 Industrial Safety Impacts from Construction and Operations (per year)

Alternative	*Estimated Number of Construction Workers*	*Estimated Number of Operations Workers*	*Construction Injuries*	*Construction Fatalities*	*Operations Injuries*	*Operations Fatalities*
No Action	0	204	0	0	6.7	0.003
TA-55 New Facility	300 (peak)	550	15.9	0.042	18	0.007
TA-6 New Facility	300 (peak)	550	15.9	0.042	18	0.007
Hybrid Facility at TA-55	300 (peak)	550	15.9	0.042	18	0.007
Hybrid Facility at TA-6	300 (peak)	550	15.9	0.042	18	0.007

As expected, the incidence of impacts, above and beyond those requiring first aid, do indeed exceed impacts from radiation accidents evaluated in this analysis. However, no fatalities would be expected from either construction or operations of any facility.

C.8 MACCS2 Code Description

The MACCS2 computer code is used to estimate the radiological doses and health effects that could result from postulated accidental releases of radioactive materials to the atmosphere. The specification of the release characteristics, designated a "source term," can consist of up to four Gaussian plumes that are often referred to simply as "plumes."

The radioactive materials released are modeled as being dispersed in the atmosphere while being transported by the prevailing wind. During transport, whether or not there is precipitation, particulate material can be modeled as being deposited on the ground. If contamination levels exceed a user-specified criterion, mitigating actions can be triggered to limit radiation exposures.

There are two aspects of the code's structure basic to understanding its calculations: (1) the calculations are divided into modules and phases, and (2) the region surrounding the facility is divided into a polar-coordinate grid. These concepts are described in the following sections.

MACCS is divided into three primary modules: ATMOS, EARLY, and CHRONC. Three phases are defined as the emergency, intermediate, and long-term phases. The relationship among the code's three modules and the three phases of exposure are summarized below.

The ATMOS module performs all of the calculations pertaining to atmospheric transport, dispersion, and deposition, as well as the radioactive decay that occurs before release and while the material is in the atmosphere. It uses a Gaussian plume model with Pasquill-Gifford dispersion parameters. The phenomena treated include building wake effects, buoyant plume rise, plume dispersion during transport, wet and dry deposition, and radioactive decay and in growth. The results of the calculations are stored for use by EARLY and CHRONC. In addition to the air and ground concentrations, ATMOS stores information on wind direction, arrival and departure times, and plume dimensions.

The EARLY module models the period immediately following a radioactive release. This period is commonly referred to as the emergency phase. The emergency phase begins at each successive downwind distance point when the first plume of the release arrives. The duration of the emergency phase is specified by the user, and it can range between one and seven days. The exposure pathways considered during this period are direct external exposure to radioactive material in the plume (cloud shine); exposure from inhalation of radionuclides in the cloud (cloud inhalation); exposure to radioactive material deposited on the ground (ground shine); inhalation of resuspended material (resuspension inhalation); and skin dose from material deposited on the skin. Mitigating actions that can be specified for the emergency phase include evacuation, sheltering, and dose-dependent relocation.

The CHRONC module performs all of the calculations pertaining to the intermediate and long-term phases. CHRONC calculates the individual health effects that result from both direct exposure to contaminated ground and from inhalation of resuspended materials, as well as indirect health effects caused by the consumption of contaminated food and water by individuals who could reside both on and off the computational grid.

The intermediate phase begins at each successive downwind distance point upon the conclusion of the emergency phase. The user can configure the calculations with an intermediate phase that has a duration as short as zero or as long as one year. In the zero-duration case, there is essentially no intermediate phase and a long-term phase begins immediately upon conclusion of the emergency phase.

Intermediate models are implemented on the assumption that the radioactive plume has passed and the only exposure sources (ground shine and resuspension inhalation) are from ground-deposited material. It is for this reason that MACCS2 requires the total duration of a radioactive release be limited to no more than four days. Potential doses from food and water during this period are not considered.

The mitigating action model for the intermediate phase is very simple. If the intermediate phase dose criterion is satisfied, the resident population is assumed present and subject to radiation exposure from ground shine and resuspension for the entire intermediate phase. If the intermediate phase exposure exceeds the dose criterion, then the population is assumed relocated to uncontaminated areas for the entire intermediate phase.

The long-term phase begins at each successive downwind distance point upon the conclusion of the intermediate phase. The exposure pathways considered during this period are ground shine, resuspension inhalation, and food and water ingestion.

The exposure pathways considered are those resulting from ground-deposited material. A number of protective measures, such as decontamination, temporary interdiction, and condemnation, can be modeled in the long-term phase to reduce doses to user-specified levels. The decisions on mitigating action in the long-term phase are based on two sets of independent actions: (1) decisions relating to whether land at a specific location and time is suitable for human habitation (habitability), and (2) decisions relating to whether land at a specific location and time is suitable for agricultural production (ability to farm).

All of the calculations of MACCS2 are stored based on a polar-coordinate spatial grid with a treatment that differs somewhat between calculations of the emergency phase and calculations of the intermediate and long-term phases. The region potentially affected by a release is represented with a (r, È) grid system centered on the location of the release. The radius, r, represents downwind distance. The angle, È, is the angular offset from north, going clockwise.

The user specifies the number of radial divisions as well as their endpoint distances. The angular divisions used to define the spatial grid are fixed in the code. They correspond to the 16 points of the compass, each being 22.5 degrees wide. The 16 points of the compass are used in the United States to express wind direction. The compass sectors are referred to as the coarse grid.

Since emergency phase calculations use dose-response models for early fatalities and early injuries that can be highly nonlinear, these calculations are performed on a finer grid basis than the calculations of the intermediate and long-term phases. For this reason, the calculations of the emergency phase are performed with the 16 compass sectors divided into three, five, or seven equal, angular subdivisions. The subdivided compass sectors are referred to as the fine grid.

Two types of doses may be calculated by the code, “acute” and “lifetime.”

Acute doses are calculated to estimate deterministic health effects that can result from high doses delivered at high dose rates. Such conditions may occur in the immediate vicinity of a nuclear facility following hypothetical severe accidents where confinement and/or containment failure has been assumed to occur. Examples of the health effects based on acute doses are early fatality, prodromal vomiting, and hypothyroidism.

Lifetime doses are the conventional measure of detriment used for radiological protection. These are 50-year dose commitments to either specific tissues (e.g., red marrow and lungs) or a weighted sum of tissue doses defined by the International Commission on Radiological

Protection and referred to as "effective dose." Lifetime doses may be used to calculate the stochastic health effect risk resulting from exposure to radiation. MACCS2 uses the calculated lifetime dose in cancer risk calculations.

C.9 REFERENCES

DOC (U.S. Department of Commerce), 1999, *State Population Projections*, 1995-2025, Bureau of the Census, Washington, DC, January 29.

DOE (U.S. Department of Energy), 1993, *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements*, Office of NEPA Oversight, Washington, DC, May.

DOE (U.S. Department of Energy), 1994a, *DOE Standard: Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports*, DOE-STD-3009-94, July (*available at http://tis.eh.doe.gov/techstds/standard*).

DOE (U.S. Department of Energy), 1994b, *DOE Handbook: Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, Vol. 1, *Analysis of Experimental Data*, DOE-HDBK-3010-94, October (*available at http://tis.eh.doe.gov/techstds/standard/standard.html*).

DOE (U.S. Department of Energy), 2000a, *DOE and Contractor Injury and Illness Experience by Operation Type by Year by Quarter - 1995 through 2000, 2nd Quarter*, Office of Environment, Safety, and Health, September 20 (*available at http://tis.eh.doe.gov/cairs/cairs/dataqtr/q002b.html*).

DOE (U.S. Department of Energy), 2000b, *DOE and Contractor Fatality Incidence Rates*, Office of Environment, Safety, and Health, November 20 (*available at http://tis.eh.doe.gov/cairs/cairs/summary/oipds002/fatrate.gif*).

DOE (U.S. Department of Energy), 2002a, *Recommendations for Analyzing Accidents under the National Environmental Policy Act*, Office of NEPA Policy and Compliance, July.

DOE (U.S. Department of Energy), 2002b, *Management Evaluation Report for the Chemistry and Metallurgy Research (CMR) Facility Basis for Interim Operations (BIO)*, Los Alamos Area Office, Los Alamos, New Mexico, August 1998.

EPA (U.S. Environmental Protection Agency), 1998, *Title III List of Lists, Consolidated List of Chemicals Subject to the Emergency Planning and Community Right-to-Know Act (EPCRA) and Section 112 (r) of the Clean Air Act, as Amended*, EPA 550-B-98-017, Office of Solid Waste and Emergency Response, Washington, DC, November.

LANL (Los Alamos National Laboratory), 2002, *Assumptions and Parameters Used for Mitigated Hazard Analysis*, CMRR Green Site, Data Call, Los Alamos, New Mexico, February.

NRC (U.S. Nuclear Regulatory Commission), 1998, *Code Manual for MACCS2: Vol. 1, User's Guide*, NUREG/CR-6613, Washington, DC, May.

Toscano, G. A., and J. A. Windau, 1998, *Compensation and Working Conditions*, *Profile of Fatal Work Injuries in 1996*, Office of Safety, Health, and Working Conditions, Bureau of Labor Statistics, Washington, DC.